AFOSR Programs in Higher Levels of Information Fusion

John F. Tangney
Directorate of Mathematics and Space Sciences
Air Force Office of Scientific Research
Arlington, Virginia USA
john.tangney@afosr.af.mil

Abstract - *The Air Force future vision for information fusion is presented in the context of results of a study of long-term challenges in the science and technology of command and control and the programs of the Air Force designed to meet them. A new approach to research is presented that takes advantage of scientific challenge problems that are operationally validated in collaboration with research laboratories in government and industry.*

Keywords: Higher Level Fusion, Fusion 2+, Research Challenges, Research Programs, Research Funding.

1 Introduction

The Air Force Office of Scientific Research (AFOSR) is the single manager of basic research for the U.S. Air Force (USAF). Basic research is defined in the U.S. Defense Department as the most fundamental of work along a research and development spectrum from knowledge discovery to technology demonstration. The AFOSR supports many areas of science, but focuses its support on topics expected strongly to contribute to the technology needs of the USAF. These programs are executed largely through grants and contracts to industrial and academic researchers.

The AFOSR program in Information Fusion, the topic of this special session, addresses fundamental issues in the ways that information can be best combined and used to support decision-making and evaluation of decision outcome. Other research funding organizations address these and similar issues, but the AFOSR program is unique for attempting to use operationally valid challenge problems to focus research and to quantify the benefits of technologies fostered by the research. The research community acting alone cannot accomplish this task. The AFOSR program involves the cooperation of technology developers and operational users in government and industry.

Other AFOSR programs relate to Information Fusion, but do not explicitly address issues of level 2 and higher fusion (See Figure 1), so are not described here in significant detail. These related AFOSR programs address issues of multi- and hyper-spectral sensing, signal processing, automatic target recognition, information assurance, guidance and control, artificial intelligence, and team command and control. A brief description of these and other programs may be found in the AFOSR Broad Agency Announcement available at www.afosr.af.mil.

0 — Sub-Object Data Association & Estimation
1 — Object Refinement
2 — Situation Refinement
3 — Impact Assessment
4 — Process Refinement

Figure 1. Levels of Information Fusion.

2 Air Force Future Vision

The AFOSR employs a number of mechanisms to help define its current and future programs. The AFOSR program in Information Fusion, for example, has relied on studies conducted by the Air Force Scientific Advisory Board (SAB) to help shape programs and relate the scientific product to future technology needs of the Air Force. This relationship between research on Information Fusion and the future technology needs is described in a number of SAB studies outlined here. (Some of these studies are available at http://www.sab.hq.af.mil.)

A seminal study of the SAB, "Report on Building the Joint Battlespace Infosphere" (JBI) [1], defines a future combat information management system that creates and maintains a common operating picture for decision support at multiple echelons. As depicted in Figure 2 and described in the report, the JBI provides a substrate for integrating existing and planned information systems for command and control, and for using the integrated result to do a lot more for intelligence preparation, operational planning, and mission assessment.

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The JBI report outlines a number of scientific and technical challenges that include some elements of communication and knowledge engineering, but the report largely focuses on issues of higher levels of Information Fusion. Specifically, the JBI report calls for technologies capable of transforming information to operational knowledge. In such contexts as intelligence preparation of the battlefield, for example, creation of a common operating picture is seen to rely on the aggregation of surveillance from diverse collection platforms and its merger with existing information on the disposition of forces, weather, and terrain features. More significantly, the JBI report outlines ways that aggregated information might be customized to user needs (as represented in models of user goals, plans, and preferences), to support planning and execution.

Figure 2. Depiction of Joint Battlespace Infosphere

The emphasis on user models in the JBI report represents a severe scientific and technological challenge and helps define the AFOSR program in Information Fusion. When available, user models largely determine 'what' to compute (as opposed to 'how' to compute, or communicate, or store knowledge – issues addressed in other related research programs) and completely determine the utility of the common operating picture. User models expressed as a number of decision rules has been estimated in certain operational contexts and is quite large, on the order of ten million rules. Using technologies currently available, approximately one million rules per year can be ascertained. This gap means that a JBI will forever remain beyond reach of current technologies because users alter their models in response to a constantly changing operational environment. The AFOSR program incorporates scientific study of methods to extract from human experts those decision rules that help determine what information ought to be fused.

Subsequent studies of the SAB have refined the JBI notion along several important lines. One SAB study conducted in 2001 and planned for release in May 2002, titled "Migration of Data Bases for Command and Control" [2], was established to addresses the need for JBI access to all data currently used in DoD systems of command and control. According to the terms of reference for this study, successful implementation of JBI will require the continued availability of legacy information systems that presumably would require their migration to a common JBI environment. The final report from this study may illuminate technical challenges in knowledge engineering but, because information technology data standards do not yet exist (and may never exist for uncontrolled data sources), the goal of AFOSR's Information Fusion program involves the creation of actionable information from data in a large variety of structures and formats.

A second recent study of the SAB explicitly addresses sensor and data information fusion to meet future operational concepts for difficult targets, such as targets that are moving or concealed or buried. A report from this study, "Sensor Technology for Difficult Targets" [3], is also scheduled for release in May 2002. It's anticipated that target types addressed in this study will require a level of knowledge and decision-making that goes beyond simple identification and recognition (i.e. that requires information fusion at levels 2 and 3), because target defeat in some cases requires exquisite modeling of the functional area or the functional site where the target is found. To address these issues of target description, the AFOSR program in Information Fusion involves the creation and maintenance of functional area models that support pre-planning, operational decision-making, plan execution, and outcome assessment.

Lastly, an ongoing study of the SAB, "Predictive Battlespace Awareness to Improve Military Effectiveness" [4], addresses processes and approaches for course of action planning that involve active management of collection resources up to and including real time sensor management. The ongoing study considers intelligence, surveillance, and reconnaissance systems whose improved management could yield improved quality of decisions. As a result, the emphasis of this study appears to involve coordination of collection resources already available rather than the definition of new information sources. To address anticipated future needs for real-time management of coordinated systems of information gathering, supervised decision-making and execution, and assessment, the AFOSR program in Information Fusion addresses cooperative planning in supervised autonomous systems.

3 Scientific Challenge Problems

As a whole, the studies of the Air Force Scientific Advisory Board listed above define a future vision for higher levels of information fusion. This vision requires new technologies to accommodate increasing volumes of information, increasing real-time management of information assets, and increasing sensitivity to the information demands of users at all echelons. The AFOSR program in Information Fusion directly addresses these issues using an approach based on challenge problems described in following sections.

The three challenge problems derive from an AFOSR-sponsored workshop, held in October 2000, that surveyed the state of technology in the context of user needs and research capabilities of government, industry, and academia. At this workshop, discussions revealed three pacing technology issues, for which significant enhancements in operational capability could be achieved by advancing identified technologies using one or another approach employed in academic research. These pacing issues are captured in the challenge problems. The workshop also revealed that operational systems for Information Fusion at higher levels either did not exist or were in a state of initial development. The lack of fielded systems suggested that a collaborative approach among stake-holding communities (of researchers, technologists, and users) might be most effective, because each community was oriented toward a future system that did not exist and whose existence would depend on technologies in need of some maturation and evolution through research.

	What You Do	What You Get
Operators	• Support System Analysis • Loan Operators to R&D	• Better, Faster, Cheaper Ops • Rapid Technology Insertion
Developers	• Build Simulator • Build Challenge Problem • Cross-Validate the Two	• Technology Certification • Technology Assessment
Researchers	• Use Challenge Problem • Exceed Benchmarks	• Common Tools • Engineering Science

Figure 3. Challenge Problem Win-Win-Win

AFOSR devised a challenge problem approach to foster collaboration between researchers, technologists, and users. To provide incentive for collaboration, the approach provides each of the constituent communities with something of value (See Figure 3). The user community provides benchmark measures of effectiveness, cooperates in technology validation, and receives field-able new technologies. The technology community establishes research challenge problems and receives a new tool for operationally valid technology assessment (this permits government laboratories to certify commercial designs). The research community addresses the challenge problems and receives a means of determining the relative significance of new discoveries. Presently, comparing research results is difficult because the dimensionality and the metric for improvements are absent. To partially alleviate this problem, properly constructed challenge problems contain operationally valid performance metrics.

The three challenge problems under development in the AFOSR program each address one of the pacing issues in higher levels of Information Fusion defined at the workshop described above. At a very general level, the pacing issues concern space (the need to automate mining of tremendous fused volumes of image and other data), time (the need for rapid dynamic re-planning among a constellation of supervised autonomous platforms), and intent (the need to adjust a common operating picture to meet changing demands of decision-making teams). Cast in this general way, the challenge problems also map to the reports of the Air Force Scientific Advisory Board outlined above – respectively, to the reports on Sensors for Difficult Targets, Predictive Battlespace Awareness, and Joint Battlespace Infosphere.

3.1 Spatial: Image Analysis

This challenge problem addresses the need to merge multiple hyper-spectral views of an area with other information about the objects in that region. The scientific issues include creation and maintenance of a common operating picture that includes high-level descriptions for functional elements under view. Technologies are needed for robustly adapting to scene changes and flexibly responding to user information needs. Work on this challenge can take advantage of other research on data storage, parallel computation, high bandwidth communications, automatic pattern recognition, inferencing, and human interface. The effectiveness of theory and modeling in this area can be assessed using measures that evaluate the computational resources required (a cost) to provide accurate and precise functional area descriptions (a benefit) using all sources of available information (a presumed benefit). The primary beneficiary of associated technology advances is the image analyst. Allen Waxman describes the current status of work on this challenge problem in the following talk [5].

3.2 Temporal: Cooperative Assessment

This challenge problem addresses the need for efficient goal-seeking behavior in a group of cooperating mobile platforms. The scientific issues include dynamic

replanning in uncertain environments and distributed knowledge management. Technologies are needed to maintain multiple hierarchical control loops and to optimize platform movements quickly in response to environmental discoveries and changing supervisory goals. Work on this challenge can take advantage of other research on sensors, signal processing, automatic target recognition, robotics, cooperative control, information assurance, and adaptive network architectures. Advances in theory and modeling in this area can be measured in terms of costs in communication bandwidth and length of travel required for limited mobile resources to build and maintain an accurate operating picture of the environment surveyed. Primary users of associated technologies do not exist today, but system developers are actively seeking design solutions for managed networks of mobile platforms. Current status of this challenge problem is described in two later talks, one by Katia Sycara [6], the other by Kevin O'Neal and Robert Murphey [7].

3.3 Intentional: Crisis Management

This challenge problem addresses the need to provide human experts with decision support and to partially automate command and control decision-making. The scientific issues concern the construction of decision rules that reflect expert intent and mimic those of human members in a command and control team. Technologies are needed to create decision rules very rapidly under expert human supervision and to implement the decision rules as a human replacement or augmentation in context of team decision-making. Work on this challenge can take advantage of related work in other scientific areas including: team command and control, cognitive science, artificial intelligence, knowledge engineering, operations research, and modeling and simulation. Advances in theory and modeling in this area can be assessed in terms of the number of human team members displaced while maintaining fixed level of control over a dynamic environment. The primary customer of associated technologies is the manager of an operational command and control center or a crisis management center. One following presentation by James Llinas [8] includes a strategy for assessing robustness of Information Fusion techniques in the context of disaster decision support, and a later presentation by Daniele Nardi and others [9] describes work on the RoboCup Rescue challenge problem for disaster monitoring.

4 Programmatics

The AFOSR program in Higher Levels of Information Fusion supports collaborations between academia, industry, government laboratories, and the user community. This program is woven into other AFOSR programs addressing many other scientific issues related to Information Fusion. Plans for support of additional research in this area include opportunities provided by programs that support research centers and collaborations between academia and industry.

4.1 Partnerships

The AFOSR establishes "Partnerships for Research Excellence and Transition" (PRET) to support research centers involving collaborations between academia and industry. The PRET centers are established in scientific areas where the pace of knowledge discovery is high and sufficiently mature to provide strong opportunities for technology development. Such a state characterizes scientific work on Information Fusion because new theories and models are often expressed in software that can be quickly inserted as modules into existing or newly designed systems for enhanced capability. Recognizing that the most promising approaches to Information Fusion have yet to be identified and that sorting among the perhaps conflicting claims of various approaches might be difficult, the PRETs for Information Fusion address challenge problems as described above. The challenge problems provide a mechanism for focusing research and for determining when scientific advances truly revolutionize current capabilities. To implement challenge problems that include operationally valid performance criteria, the AFOSR has enhanced the typical PRET for Information Fusion to include collaborators from the user community and certain Technology Directorates of the Air Force Research Laboratory. The remainder of this special session includes presentations by scientific and technological collaborators in PRET activity. As described above, these presentations describe the collaborative activity of partners in academia, industry, and government representing researchers, technologists, and users.

4.2 Woven Disciplines

Many scientific disciplines contribute to advanced capability for Information Fusion or are required to implement functional systems. In other programs, the AFOSR supports research in many disciplines related to Information Fusion and maintains relationships with those programs through joint workshops, visits, and exchanges of personnel. The few examples that follow illustrate that the science of Information Fusion can take advantage of advances in other areas and that implementations of Fusion technologies may require advances in certain other disciplines. Work on team performance, for example, can provide the Fusion community with specification of an operating picture and with description of how team members best operate for fast accurate decision-making. Work on Sensors, Automatic Target Recognition, and Tracking can provide more robust inputs to the fusion

process and offload requirements for sophisticated inferencing that would otherwise involve fused information. Work on guidance and control of autonomous vehicles can provide standards for interactive control of these vehicles by fusion-based management systems. Work on communications, including information assurance, can provide bandwidth that might be required to construct and deliver a common operating picture. Lastly, work on large databases and knowledge engineering can provide needed repositories for the grist of fusion mills. To better link advances in these disciplines with those in Information Fusion, the maturation and delivery of the challenge problems remains a high priority in this program.

4.3 Program Plans

The AFOSR plans to increase support for research on higher levels of information fusion through funding of additional research centers, smaller collaborations between academia and industry, and international research. Opportunity to propose additional centers may be offered through the Multidisciplinary Research Program of the University Research Initiative (MURI) typically announced during the summer of each year. The MURI centers involve academic institutions only, funded up to one million per year for up to five years. Opportunities for smaller collaborations between academia and industry may be provided through the Small Business Technology Transfer (STTR) program typically announced at the beginning of each calendar year. This program provides up to $600K in early stage research and development funding directly to small companies working cooperatively with researchers at universities and other research institutions. International research is supported under the AFOSR "International Research Initiatives" program. This program is announced annually, usually in the fall, and supports efforts such as that presented later in this session by collaborators at the University of Rome, Italy.

As the challenge problems mature, the AFOSR plans to increase coordination with other Federal funding agencies that provide funding for research and technology development in higher levels of information fusion.

5 Summary

The AFOSR program in Higher Levels of Information Fusion supports research directed at future Air Force needs conveyed in recent reports of the Air Force Scientific Advisory Board. The program implements research challenge problems to focus multidisciplinary research in this area and to establish metrics for comparing the magnitude of new findings. Implementation of challenge problems with operational validity requires research collaboration with government laboratories and the user community. AFOSR supports these needed collaborations through "Partnerships for Research Excellence and Transition" combined with other funding mechanisms, and plans to expand its support for research on higher levels of information fusion.

The current scope of AFOSR's program in Higher Levels of Information Fusion is illuminated by the several papers that follow in this special session.

References

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[5] Allen Waxman, *Information Fusion for Image Analysis*, presented at Fusion 2002, Annapolis MD, 2002.

[6] Katia Sycara, *From Data to Actionable Knowledge and Decision*, paper presented at Fusion 2002, Annapolis MD, 2002.

[7] Kevin O'Neal & Robert Murphey, *The Cooperative Attack Testbed*, paper presented at Fusion 2002, Annapolis MD, 2002.

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[9] Fabrizio D'Agostino *etal*, *Monitoring and Information Fusion for Search and Rescue Operations in Large-Scale Disasters*, paper presented at Fusion 2002, Annapolis MD, 2002.